

"Never forget that a small group of dedicated individuals can change the world. Indeed, nothing else ever has."

—Margaret Mead

Introduction

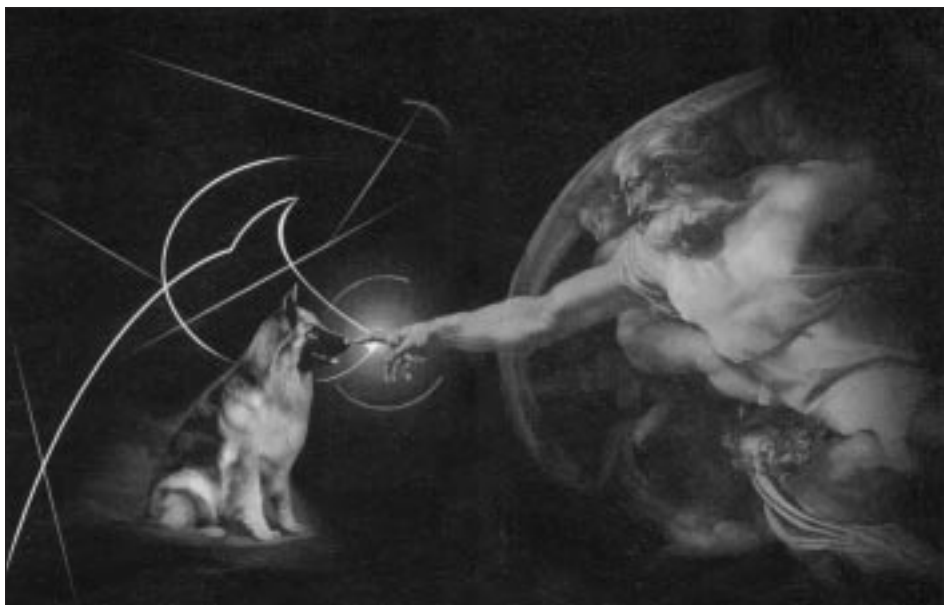
In 1997, the Defense Advanced Research Projects Agency (DARPA) accepted a great challenge. The post-conflict problem presented by landmines had achieved notoriety as a problem of global humanitarian importance. The international community estimated that more than 100 million landmines were buried in approximately 60 countries, which represented a considerable military challenge. Reports from U.S. field soldiers consistently listed landmines as one of the top three threats they faced in Bosnia. In fact, during the Bosnia conflict, more than 2 million landmines were laid in a country less than half the size of Colorado. As a result, mine detection had taken on great urgency.

The problem of landmines, however, is not new. "For the last 60 years, a sharply increasing percentage of American soldiers have been killed or wounded by landmines. From World War II to Somalia, the percentage of casualties caused by landmines has grown from 2.5 percent to 26 percent," noted LTG Paul J. Kern, Military Deputy to the Assistant Secretary of the Army for Acquisition, Logistics and Technology.

Although there had been some technological progress in landmine detection, the problem was made more difficult by the wide-scale production of cheap, low-metal-content plastic mines. The best mine detection systems available in 1997 were technologically superior to the 1940s-style metal detector, but only barely. Indeed, the only landmine detection equipment issued to U.S. soldiers in the field were the metal detector and a sharp, pointy stick. In conflicts around the world, landmines were going in the ground at a rate of millions per year and were only being removed at a rate of hundreds of thousands per year—in a good year. Further, for every 5,000 landmines removed, one deminer was killed or maimed. The United States was falling behind and in desperate need of a technological breakthrough in landmine detection.

Background

DARPA's goal in 1997 was to develop a new mine detector with unparalleled performance. We (DARPA) began with an idea from humble origins—the dog. Canines are exquisitely good at landmine detection and are able to search for the explosive material itself. This dramatically decreases the advent of false alarms. Indeed, if we could find a way to search for the explosive material itself, we could fundamentally change landmine detection.



THE MAKING OF A DOG'S NOSE

Dr. Regina E. Dugan

Conventional mine detection involves searching for features associated with the mine, such as small changes in the electric or optical properties or the small amount of metal associated with the fire pin. As a result, there are approximately 1,000 or more false alarms for every actual mine found. Nature causes many changes in electric and optical properties, and there are many small pieces of metal anywhere humans have been. All of these seriously confound traditional sensors. Philosophically, a more robust solution was to search for what was unique to the mine.

Chemically Specific Detection

Canines provided the incentive for our idea: chemically specific detection via the explosive material. But, humans are capable of many creative interpretations of biology. DARPA devised many engineering designs. Some were based only on the overarching principle of chemically specific detection, while others mimicked the actual design of the biological system. Indeed, there is something fundamental that nature has taught us about odor detection. The biological system uses a broadband array of sensors, none specific to the chemical of interest. Dogs do not have trinitrotoluene (TNT)-specific sensors. Rather, they use a sensitive but highly cross-reactive array of sensors and provide for high-fidelity processing of the signals from this array.

It is this processing that provides for the capability to learn new odors. You may never have smelled orange juice, cut grass, or full-bodied wine, but the mammalian olfactory system has the ability to discern, learn, and remember new and complex odors. This, combined with a well-designed and adapted sampling system, provides for the miracle of mammalian olfaction.

Research And Development

With this basic approach, we set out to build new landmine detection systems to serve those in the field. In our pursuit of this goal, we focused not only on the technical tasks before us, but also on the people we were serving. To develop something of use, our researchers had to understand the problem; they had to understand our customer. Therefore, we took them to the field—again and again. We constructed a 22-acre, state-of-the-art experimental facility at Fort Leonard Wood, MO, home of the U.S. Army Engineer School. Because this facility was constructed to test explosive detection systems, it allowed us to move systems out of the laboratory and into the field quickly. It also allowed us to be close to our customer.

We showed our researchers how landmine detection is accomplished now, from breaching to probing. We had Ph.D.s use metal detectors and pointy sticks to search for booby-trapped mines. We taught them about the threat and had them talk to sergeants and generals. A subset of the



Dog's Nose Program researchers learn mine-clearance techniques.

researchers visited actual operational fields—humanitarian mine-clearance efforts in Mozambique and Bosnia—and brought the message back to the group. We worked to ensure that the problem was realistically identified and that we understood what was happening in the field—to Mozambican deminers, to Bosnians, and to our soldiers and Marines. We put faces and names on the problem and made it personal because we believed that the ultimate test of success would be measured by the confidence and enthusiasm of the user.

We built a team through common experiences and common purpose. Their commitment broke down institutional barriers and interdisciplinary work became more exciting. The team of researchers worked nights and weekends to solve the landmine detection problem. They were absolutely uncompromising; good enough simply wasn't.

Quadrupole Resonance System

In the 3 short years of the program, detection of underground explosives was successfully demonstrated using three different prototype systems, both in the laboratory and in the field against real explosives buried in the ground. With our quadrupole resonance system, which is not explicitly a mammalian olfaction design, we can now detect very small amounts of explosives, the size of antipersonnel mines, with near-perfect detection rates and almost no false alarms.

The improvements in system performance increased dramatically. In 1997, we were able to detect hundreds of grams of RDX; in 1999, we were able to detect as few as 10 grams. The detection of small quantities of TNT is the Holy Grail of mine detection, and the ability to detect TNT using

quadrupole resonance was largely believed to be impossible. In December 1999, this last scientific obstacle fell. The prototype quadrupole resonance system was tested at the U.S. Army Engineer School. The prototype system detected 100 percent of all TNT, RDX, and plastic and metal mines with no false alarms after a single rescan of initial alarms. Detection of TNT in the field using quadrupole resonance technology *was* possible after all.

Electronic Noses

We also had two electronic noses sniff landmines underground. The initial field results must be reproduced, improved, and verified, but the principle is proven—one can construct a sensor to detect a landmine via its chemical signature. We have demonstrated detection sensitivities 10,000-fold greater than current airport security sniffers. Another system is able to determine not only the presence of a landmine, but also the odor of the local environment. The sensor learns the smell of the ground and is able to adapt to new field settings. It provides a rich "image" of smell.

Recently, researchers exposed an electronic nose to a variety of odors and recorded the response in a two-dimensional digital movie. The movie shows the changing response across an array of sensors to a variety of chemicals as changing colors. In other words, it allows a human to *see* odors. These nose technologies promise to revolutionize chemical sensing in warfare environments. The first goal is landmine detection, but the future impact of providing a soldier with the olfactory acuity of a canine has not yet been realized.

A great challenge for any revolutionary technology development is transition to the user. While it is necessary to prove the basic principles in prototypes, it is not sufficient. Transition requires a whole new set of participants dedicated to the fielding of equipment, and the timing of these transitions is critical. In DARPA's rapid-pace developments, there is often little time for a graceful transition.

Other Programs

The most important breakthroughs in the Dog's Nose Program occurred at the end of the third year. Just 1 year earlier, we did not know if the objectives of the program were achievable. Despite the late-breaking developments, the Project Manager for Mines, Countermine and Demolitions began an aggressive \$12 million, 3-year program to further develop and field quadrupole resonance equipment for landmine detection on roads. As part of this effort, the U.S. Army Communications-Electronics Command Night Vision and Electronics Sensors Directorate initiated an immediate multimillion dollar science and technology "bridge" program to address the most critical technical challenges for using quadrupole resonance technology on vehicles. Simultaneously, the U.S. Marine Corps, in cooperation with the Office of Naval Research, laid out a program to field quadrupole resonance for hand-held detection applications.

Conclusion

As a result of these efforts, LTG Paul J. Kern commented, "We enter the 21st century with new optimism. Quadrupole resonance technology holds great promise for our soldiers because it will detect a mine in place and eliminate the need to conduct exceedingly dangerous manual probing. We finally have a viable solution to a problem that has indiscriminately plagued soldiers and civilians for more than 6 decades."

Throughout this program, individuals with courage and commitment made the difference. During the last 3 years, a group of heroic scientists and engineers, soldiers and Marines, and civilians and contractors waged a quiet battle against landmines. And they won.

DR. REGINA E. DUGAN is a Program Manager at DARPA. She was selected as DARPA Program Manager of the Year in 1999. Dugan has a B.S. and an M.S. from Virginia Polytechnic Institute and a Ph.D. from California Institute of Technology, all in mechanical engineering.
